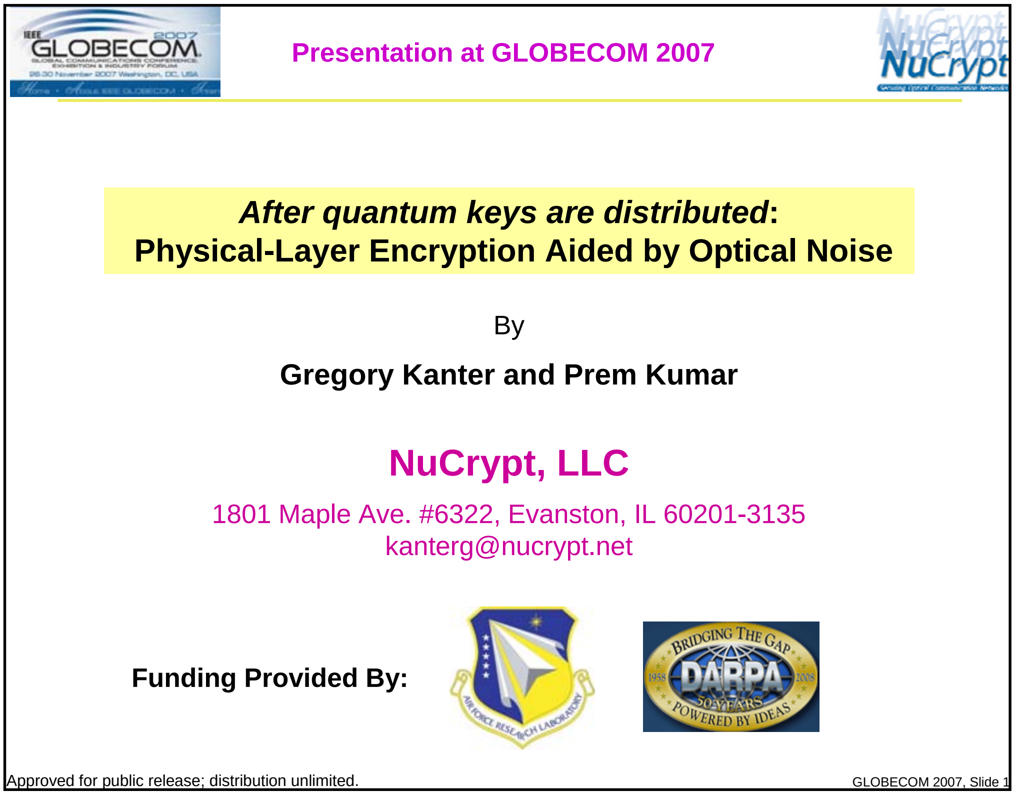

Presentation at GLOBECOM 2007

After quantum keys are distributed: Physical-Layer Encryption Aided by Optical Noise

By

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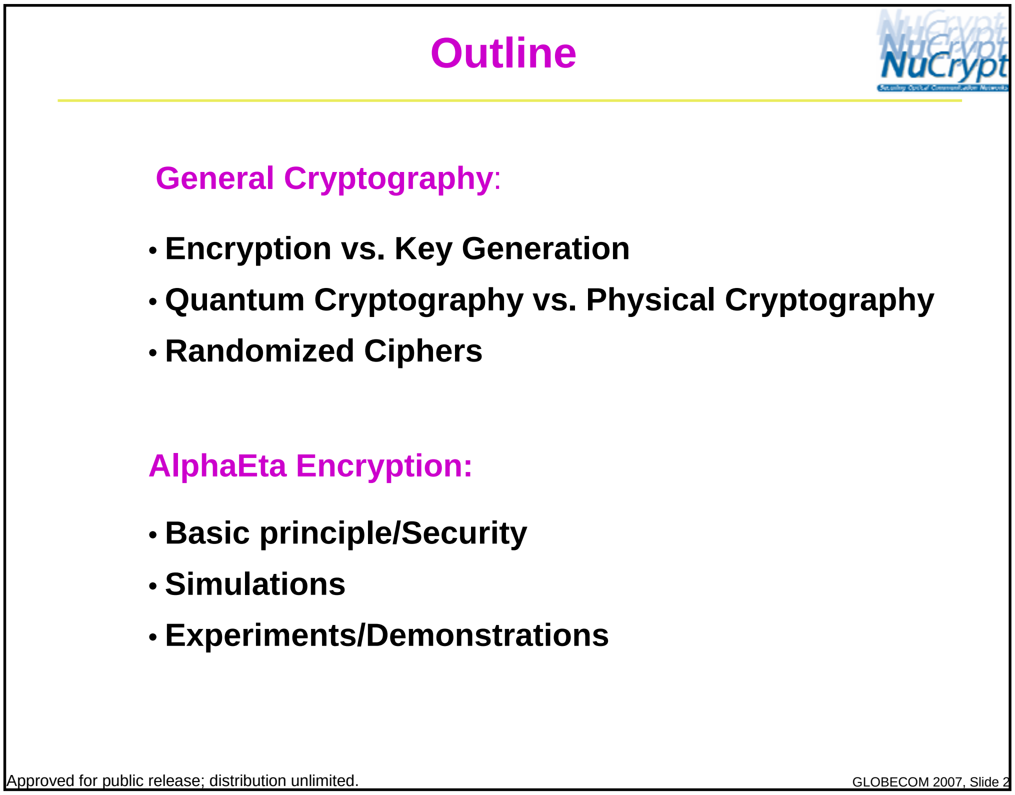

Outline

General Cryptography:

- Encryption vs. Key Generation
- Quantum Cryptography vs. Physical Cryptography
- Randomized Ciphers

AlphaEta Encryption:

- Basic principle/Security
- Simulations
- Experiments/Demonstrations

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1. REPORT DATE **2007**	2. REPORT TYPE	3. DATES COVERED **00-00-2007 to 00-00-2007**

4. TITLE AND SUBTITLE **After quantum keys are distributed: Physical-Layer Encryption Aided by Optical Noise**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **NuCrypt, LLC,1801 Maple Ave. #6322,Evanston,IL,60201-3135**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

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13. SUPPLEMENTARY NOTES

EEE Global Telecommunications Conference (IEEE GLOBECOM 2007), 26-30 November 2007, Washington, DC

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

Standard Form 298 (Rev. 8-98)
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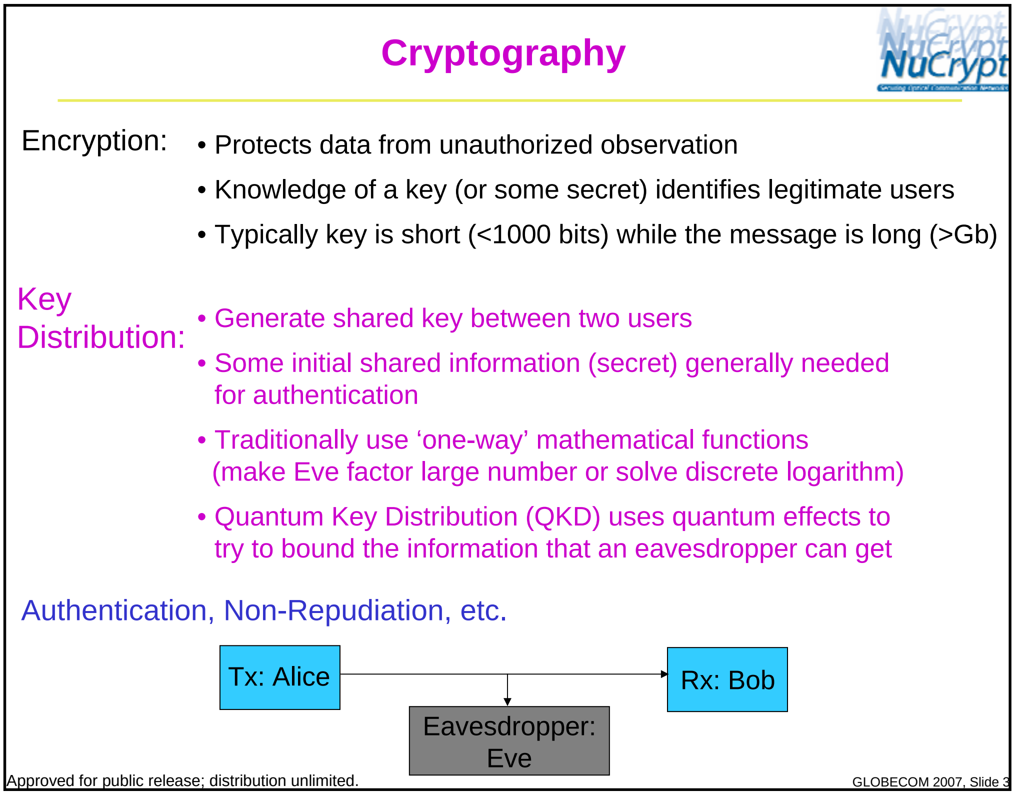

Cryptography

Encryption:

- Protects data from unauthorized observation
- Knowledge of a key (or some secret) identifies legitimate users
- Typically key is short (<1000 bits) while the message is long (>Gb)

Key Distribution:

- Generate shared key between two users
- Some initial shared information (secret) generally needed for authentication
- Traditionally use 'one-way' mathematical functions (make Eve factor large number or solve discrete logarithm)
- Quantum Key Distribution (QKD) uses quantum effects to try to bound the information that an eavesdropper can get

Authentication, Non-Repudiation, etc.

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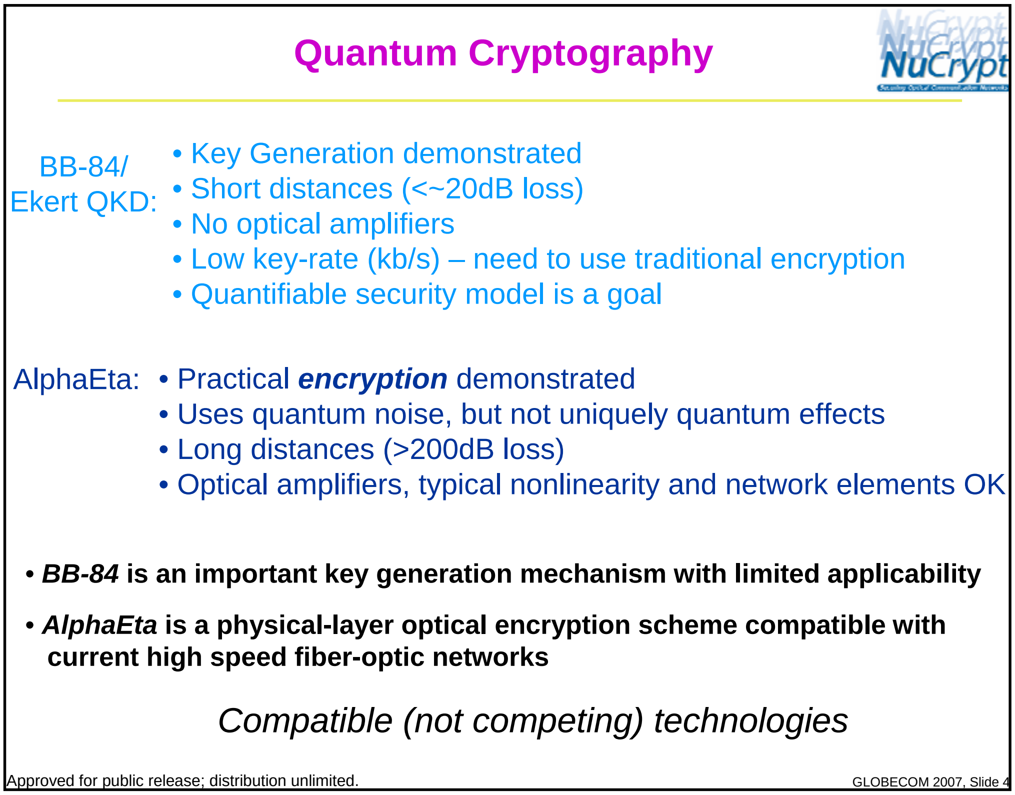

Quantum Cryptography

BB-84/ Ekert QKD:

- Key Generation demonstrated
- Short distances (<~20dB loss)
- No optical amplifiers
- Low key-rate (kb/s) – need to use traditional encryption
- Quantifiable security model is a goal

AlphaEta:

- Practical ***encryption*** demonstrated
- Uses quantum noise, but not uniquely quantum effects
- Long distances (>200dB loss)
- Optical amplifiers, typical nonlinearity and network elements OK

- ***BB-84*** **is an important key generation mechanism with limited applicability**
- ***AlphaEta*** **is a physical-layer optical encryption scheme compatible with current high speed fiber-optic networks**

Compatible (not competing) technologies

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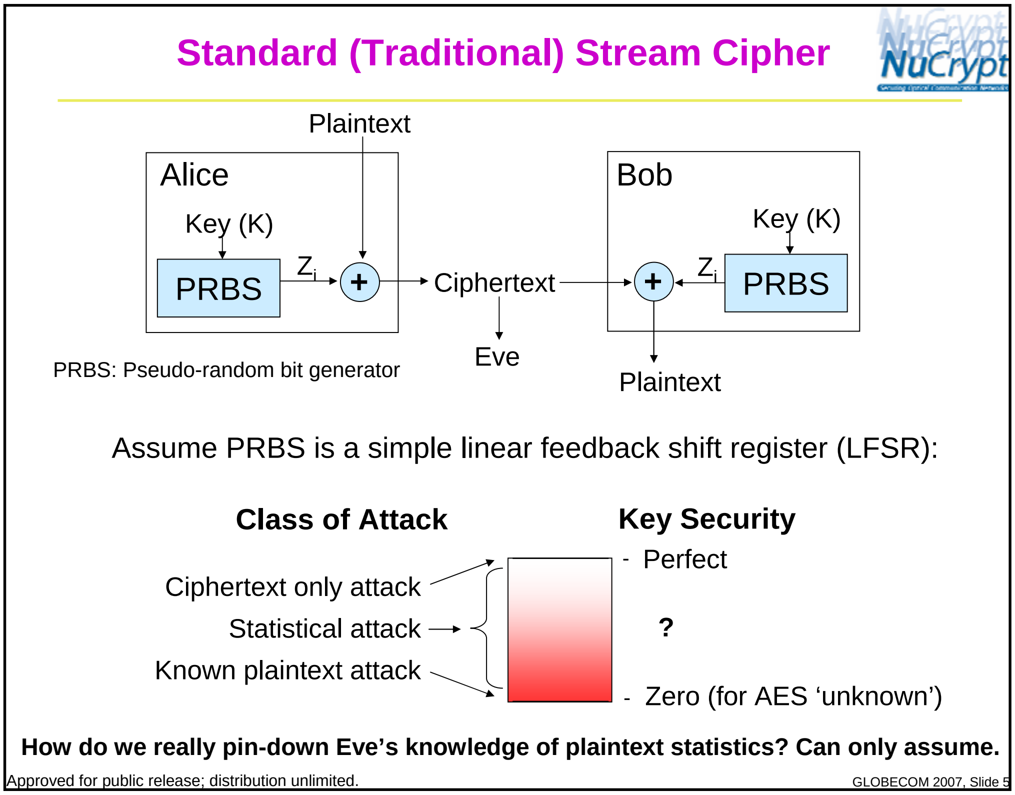

Standard (Traditional) Stream Cipher

PRBS: Pseudo-random bit generator

Assume PRBS is a simple linear feedback shift register (LFSR):

Class of Attack	Key Security
Ciphertext only attack	- Perfect
Statistical attack	?
Known plaintext attack	- Zero (for AES ‘unknown’)

How do we really pin-down Eve’s knowledge of plaintext statistics? Can only assume.

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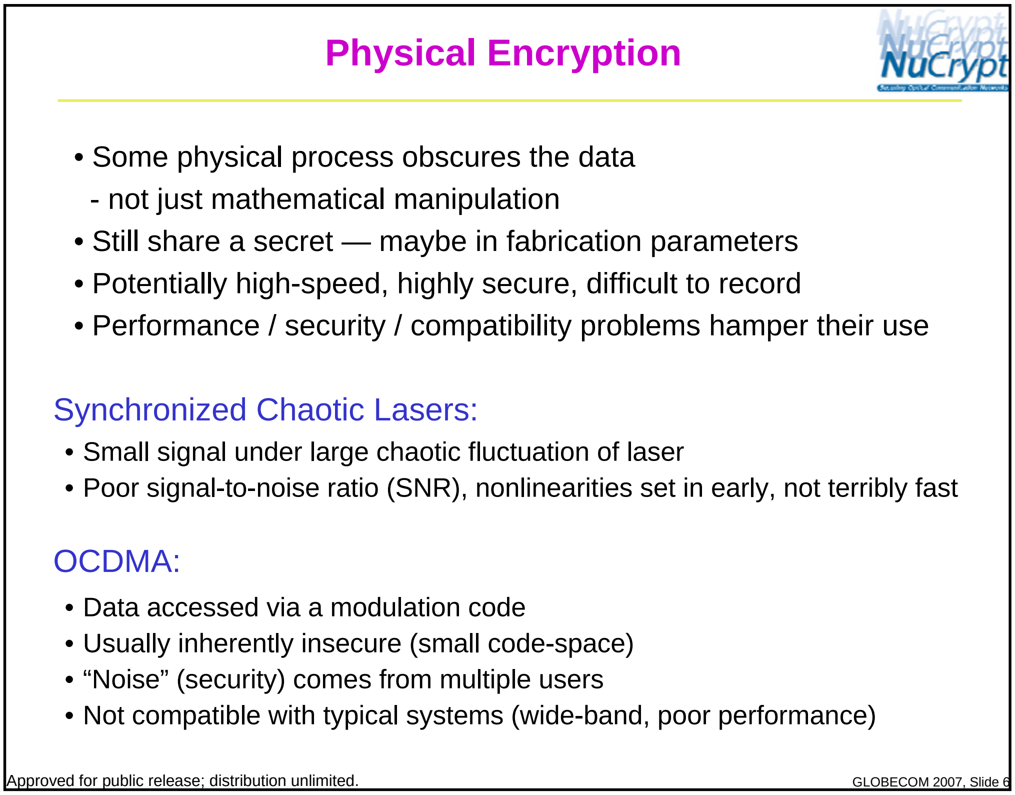

Physical Encryption

- Some physical process obscures the data
  - not just mathematical manipulation
- Still share a secret — maybe in fabrication parameters
- Potentially high-speed, highly secure, difficult to record
- Performance / security / compatibility problems hamper their use

Synchronized Chaotic Lasers:

- Small signal under large chaotic fluctuation of laser
- Poor signal-to-noise ratio (SNR), nonlinearities set in early, not terribly fast

OCDMA:

- Data accessed via a modulation code
- Usually inherently insecure (small code-space)
- “Noise” (security) comes from multiple users
- Not compatible with typical systems (wide-band, poor performance)

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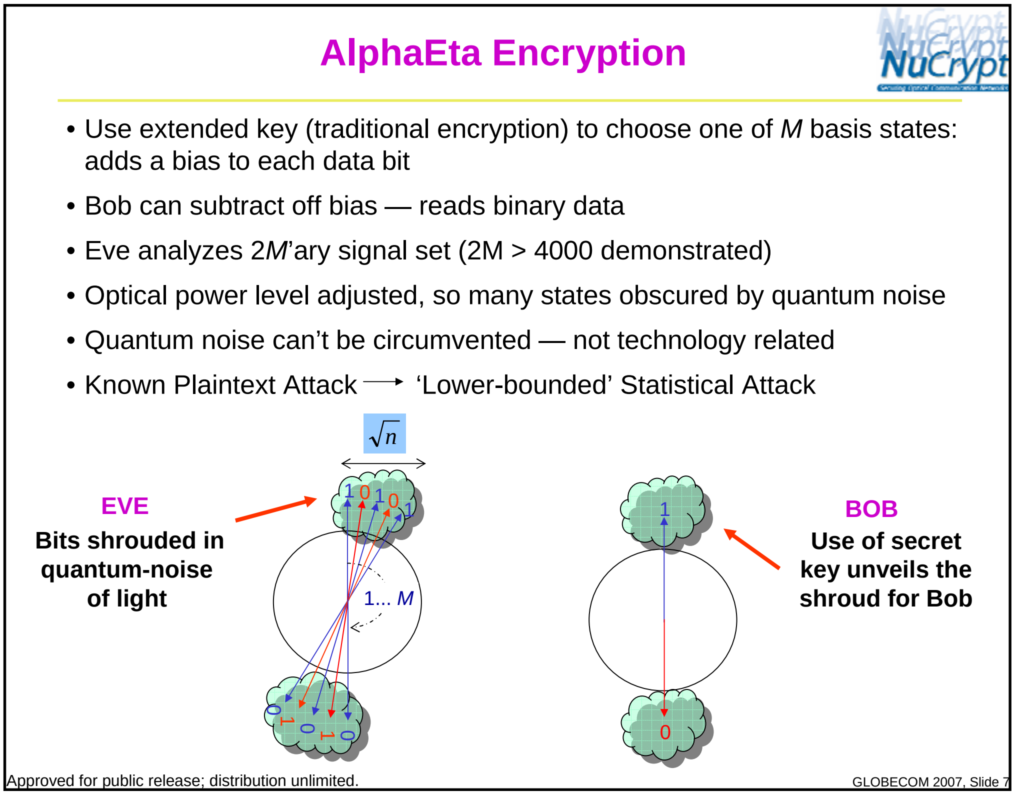

AlphaEta Encryption

- Use extended key (traditional encryption) to choose one of *M* basis states: adds a bias to each data bit
- Bob can subtract off bias — reads binary data
- Eve analyzes 2*M*'ary signal set (2M > 4000 demonstrated)
- Optical power level adjusted, so many states obscured by quantum noise
- Quantum noise can't be circumvented — not technology related
- Known Plaintext Attack → 'Lower-bounded' Statistical Attack

EVE
Bits shrouded in quantum-noise of light

BOB
Use of secret key unveils the shroud for Bob

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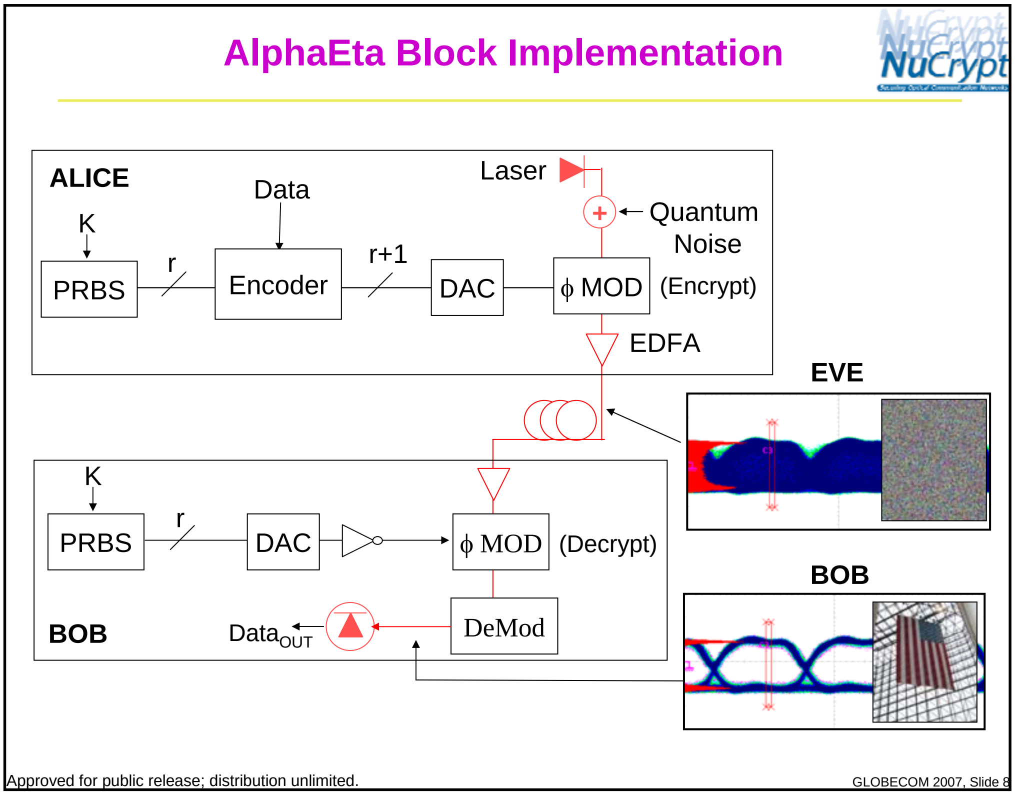

AlphaEta Block Implementation

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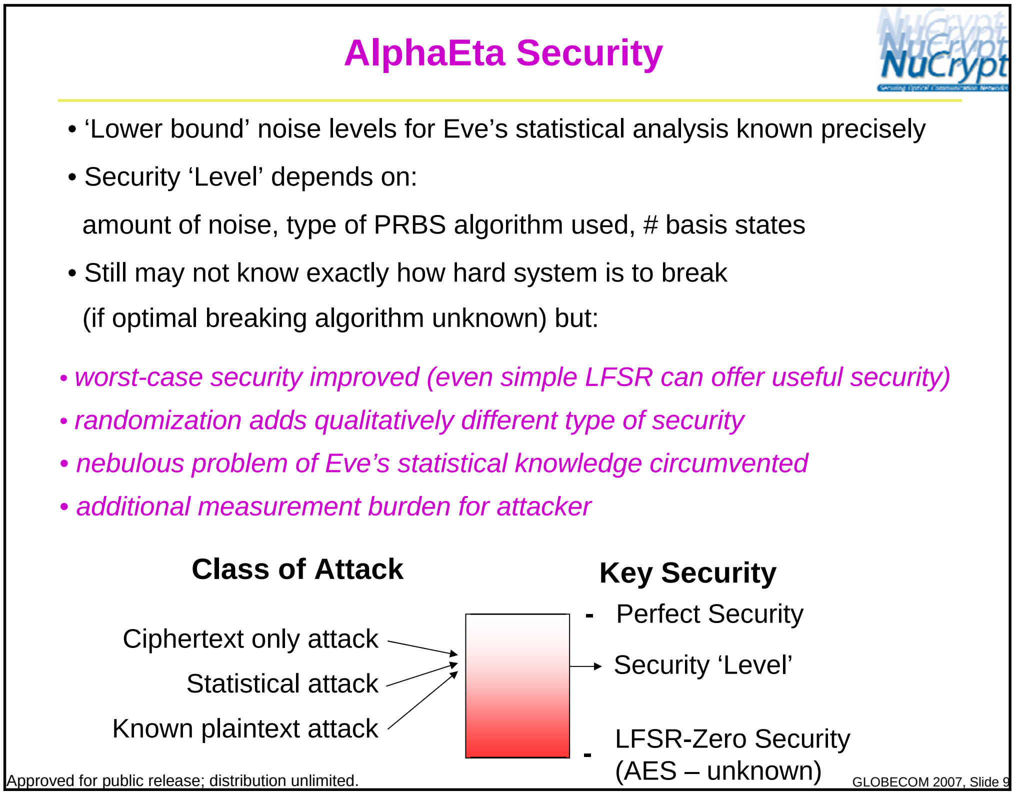

AlphaEta Security

- ‘Lower bound’ noise levels for Eve’s statistical analysis known precisely
- Security ‘Level’ depends on:

  amount of noise, type of PRBS algorithm used, # basis states
- Still may not know exactly how hard system is to break

  (if optimal breaking algorithm unknown) but:

- *worst-case security improved (even simple LFSR can offer useful security)*
- *randomization adds qualitatively different type of security*
- *nebulous problem of Eve’s statistical knowledge circumvented*
- *additional measurement burden for attacker*

Class of Attack

Ciphertext only attack

Statistical attack

Known plaintext attack

Key Security

- Perfect Security

Security ‘Level’

- LFSR-Zero Security (AES – unknown)

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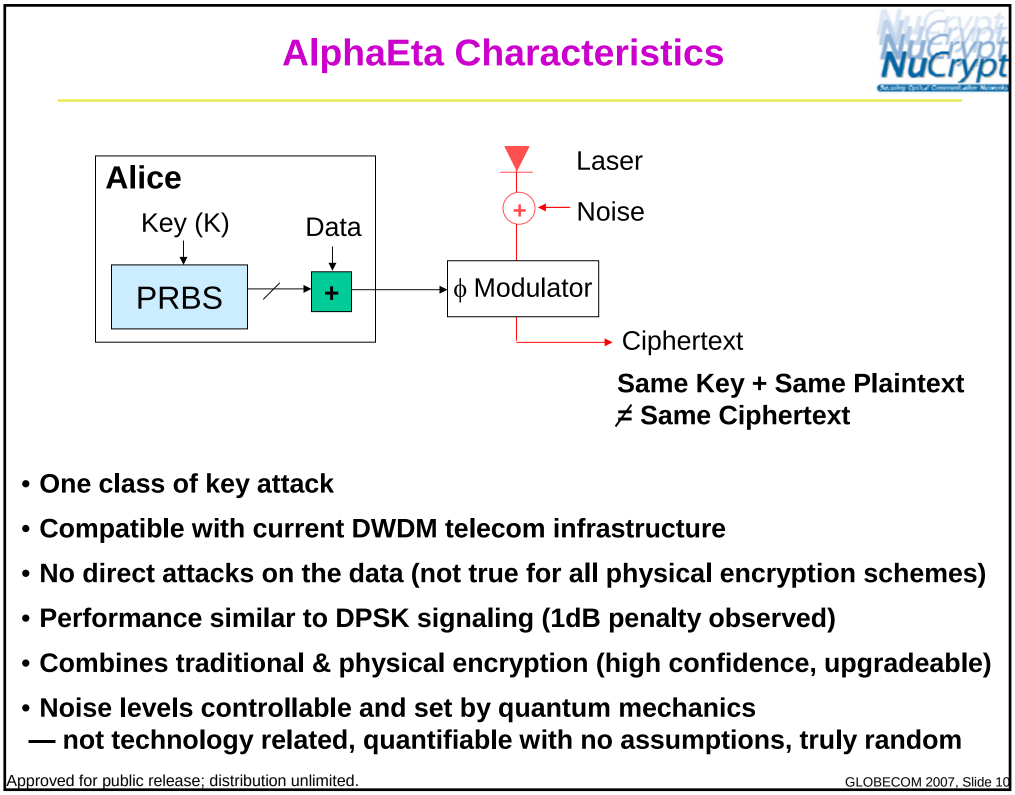

AlphaEta Characteristics

Same Key + Same Plaintext
≠ Same Ciphertext

- **One class of key attack**
- **Compatible with current DWDM telecom infrastructure**
- **No direct attacks on the data (not true for all physical encryption schemes)**
- **Performance similar to DPSK signaling (1dB penalty observed)**
- **Combines traditional & physical encryption (high confidence, upgradeable)**
- **Noise levels controllable and set by quantum mechanics**
  — not technology related, quantifiable with no assumptions, truly random

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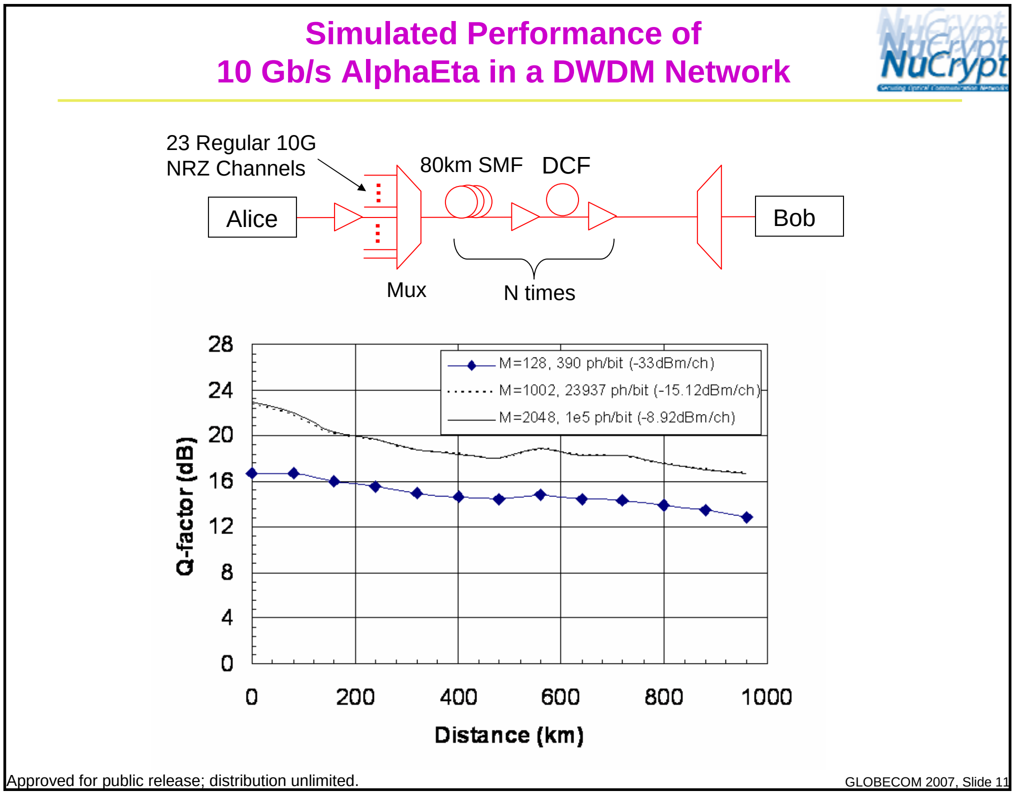

Simulated Performance of 10 Gb/s AlphaEta in a DWDM Network

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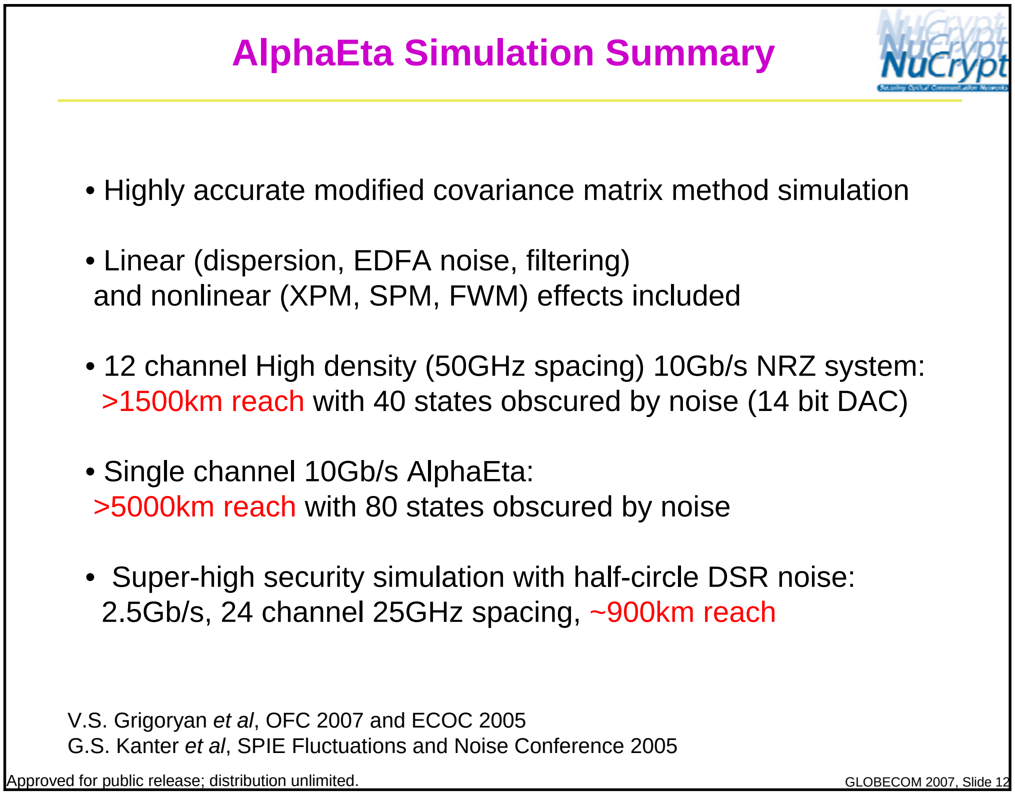

AlphaEta Simulation Summary

- Highly accurate modified covariance matrix method simulation
- Linear (dispersion, EDFA noise, filtering) and nonlinear (XPM, SPM, FWM) effects included
- 12 channel High density (50GHz spacing) 10Gb/s NRZ system: >1500km reach with 40 states obscured by noise (14 bit DAC)
- Single channel 10Gb/s AlphaEta: >5000km reach with 80 states obscured by noise
- Super-high security simulation with half-circle DSR noise: 2.5Gb/s, 24 channel 25GHz spacing, ~900km reach

V.S. Grigoryan *et al*, OFC 2007 and ECOC 2005
G.S. Kanter *et al*, SPIE Fluctuations and Noise Conference 2005

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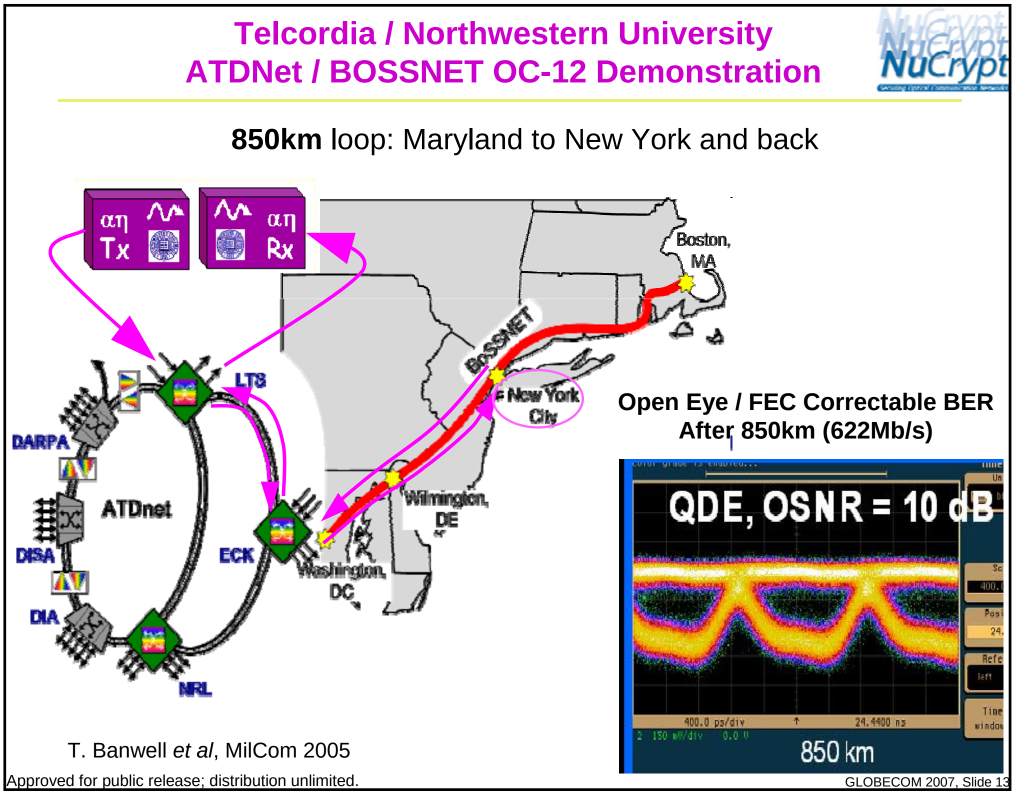

Telcordia / Northwestern University ATDNet / BOSSNET OC-12 Demonstration

850km loop: Maryland to New York and back

Open Eye / FEC Correctable BER After 850km (622Mb/s)

T. Banwell *et al*, MilCom 2005

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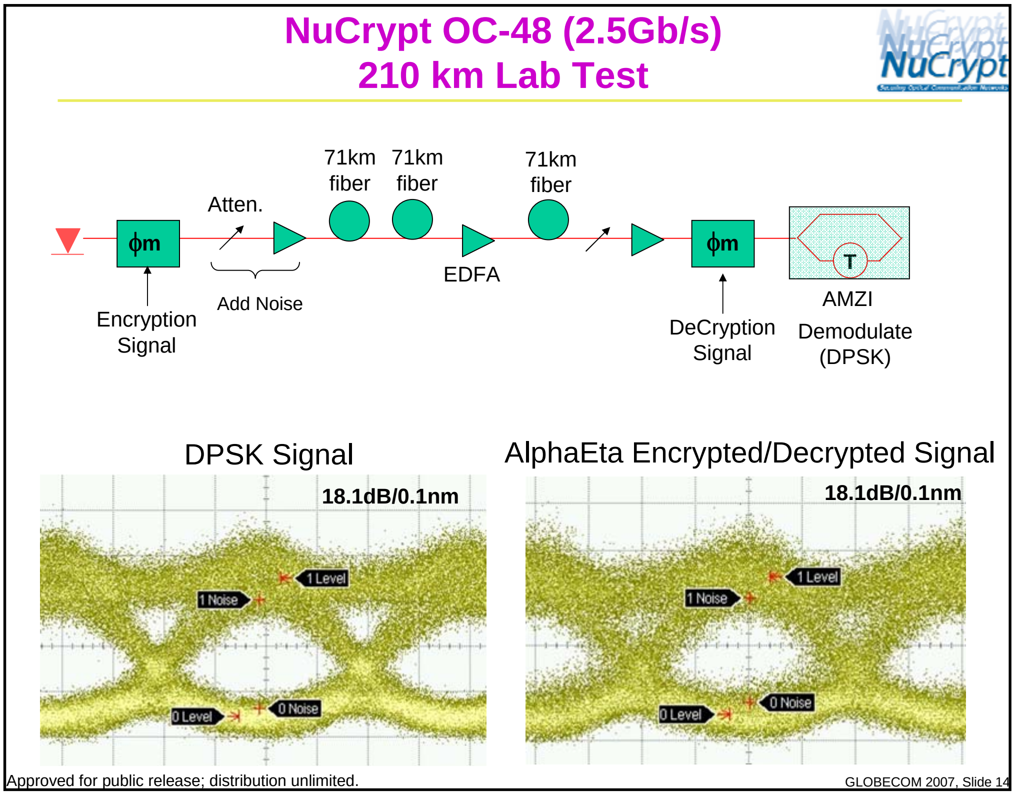

NuCrypt OC-48 (2.5Gb/s) 210 km Lab Test

DPSK Signal

AlphaEta Encrypted/Decrypted Signal

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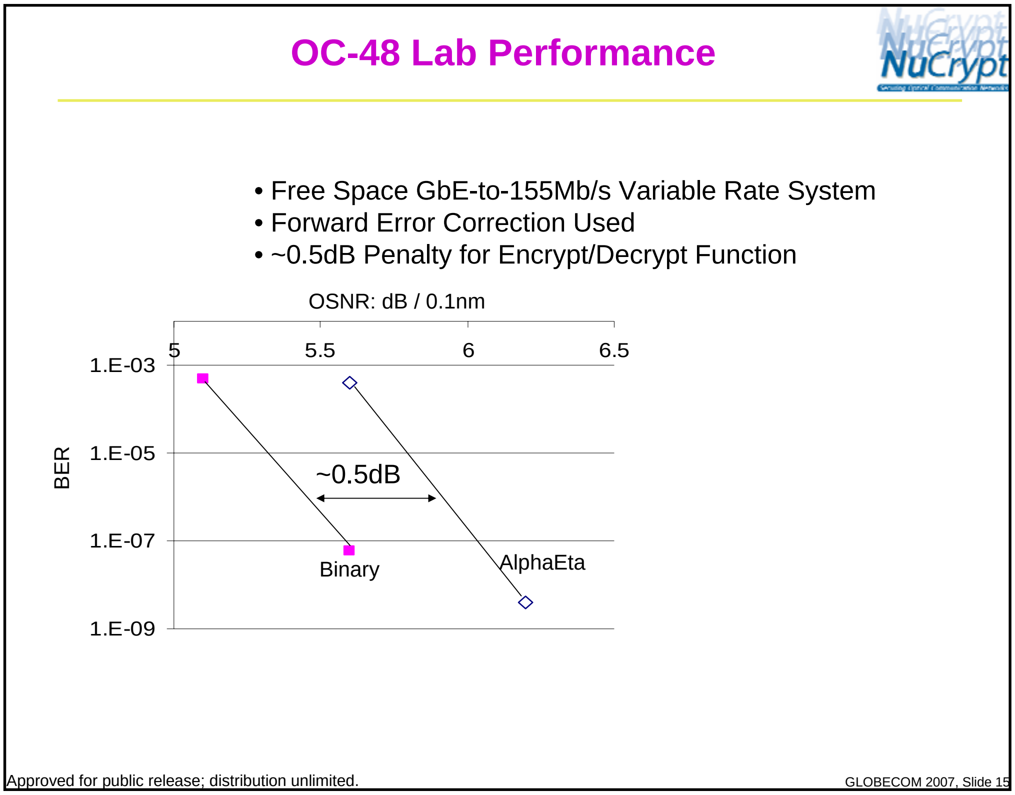

OC-48 Lab Performance

- Free Space GbE-to-155Mb/s Variable Rate System
- Forward Error Correction Used
- ~0.5dB Penalty for Encrypt/Decrypt Function

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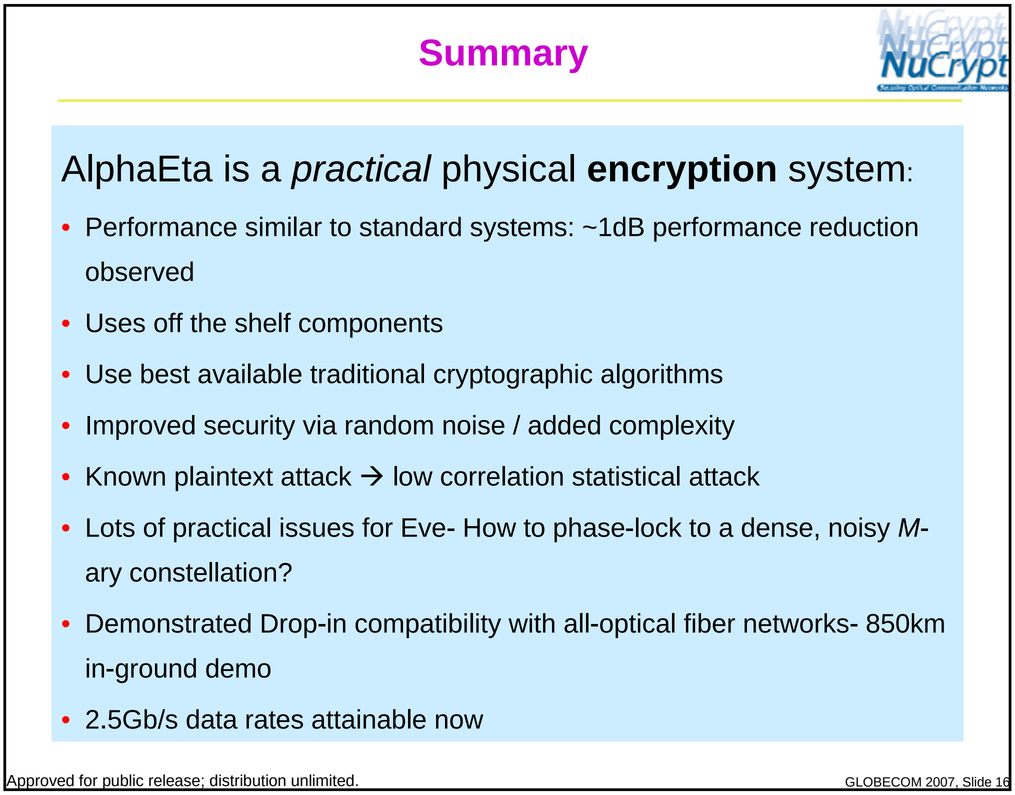

Summary

AlphaEta is a *practical* physical **encryption** system:

- Performance similar to standard systems: ~1dB performance reduction observed
- Uses off the shelf components
- Use best available traditional cryptographic algorithms
- Improved security via random noise / added complexity
- Known plaintext attack → low correlation statistical attack
- Lots of practical issues for Eve- How to phase-lock to a dense, noisy *M*-ary constellation?
- Demonstrated Drop-in compatibility with all-optical fiber networks- 850km in-ground demo
- 2.5Gb/s data rates attainable now

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